APPENDIX C4

the Coffee Brewing Handbook

First Edition

by Ted R. Lingle

A Systematic Guide to Coffee Preparation

ABOUT THE AUTHOR

Ted R. Lingle was born and raised in Southern California. He graduated from the United States Military Academy in 1966 and served four years on active duty in both Germany and Vietnam. He has an MBA degree from Woodbury University in Los Angeles.

During his twenty year coffee career, Ted was V.P.-Marketing for Lingle Bros. Coffee, Inc., a coffee roaster started in 1920. He directed the company's sales programs for the food service, office coffee service, and specialty coffee market segments from 1970 to 1990.

Mr. Lingle served as a member of the National Coffee Association's Out-of-Home Market Committee from 1974 to 1990. He served on the Board of Directors of the National Coffee Service Association and was elected an Honorary Member in 1990. He was one of the founding co-chairmen of The Specialty Coffee Association of America.

Mr. Lingle played a key role in the formation and growth of the Coffee Development Group (CDG). He was the first chairman of the College Campus Task Force. Later, he was the first chairman of the Foodservice Education Task Force. He served on CDG's Board of Directors and as its Chairman in 1985-86.

In 1975, Mr. Lingle pioneered the development of the coffee Conductivity Meter, an electronic instrument used for the measurement of soluble solids. In 1985, he wrote the *Coffee Cuppers' Handbook* to promote the discussion of more meaningful and accurate coffee flavor terminology. As author of the *Coffee Cuppers' Handbook,* written to assist new specialty coffee retail roasters, Ted combines the traditions of the cupping table with the science of flavor chemistry to help teach the art and science of sensory analysis that coffee roasters employ in their craft.

In 1995, he wrote the *Coffee Brewing Handbook* to promote excellence in beverage preparation. As author of the *Coffee Brewing Handbook,* written to assist new specialty coffee cafe operators, Ted pulls together the past fifty years of research on coffee brewing to help these coffee merchants understand how to maximize the potential of the high quality coffee beans they buy. Properly brewed coffee is the result of identifying and controlling key variables. Those who develop this coffee skill will become true masters of their craft.

On July 1, 1991, Ted R. Lingle was appointed Executive Director of the Specialty Coffee Association of America. As the first full-time staff member of SCAA, he helped guide the Association's activities during its remarkable growth from 350 members in 1991 to over 2,400 members in 1995.

THE COFFEE BREWING HANDBOOK

A Systematic Guide to Coffee Preparation

by
Ted R. Lingle

Specialty Coffee Association of America
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The Specialty Coffee Association of America is a
non-profit trade association dedicated to fostering
coffee excellence through education and information exchange.

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CHAPTER 1
ESSENTIALS OF GOOD BREWING

Although you purchase roasted coffee either in its whole bean or ground form, you consume it as a beverage. Therefore, the quality of the coffee relates directly to your ability to transform it into an enjoyable beverage. To make the beverage flavorful, you must observe the six essential elements of good brewing practices.

Coffee begins this transformation as a green bean. The beans come from many growing regions around the world, each with its own distinctive flavor characteristics. Often the green beans are blended. The types of beans and the proportion in which they are blended largely determine the flavor found in the beverage. The way beans are roasted—including the rate and length of heating—also plays a critical role in determining the ultimate flavor of the brew.

Before they can be brewed, however, the beans must be ground into small particles that range in size from slightly coarse to extremely fine. A specified portion of these coffee particles is then immersed in a predetermined portion of water. The size of the particles, the specific ratio of coffee to water, the time the coffee is in contact with the water, and the quality of brewing water all affect the flavor.

The Flavor of Coffee

Coffee gets most of its flavor from the great variety of chemical compounds released when the ground particles make contact with water. Under normal circumstances, the water extracts about 80% of the available water-soluble, flavoring compounds, which constitute the beverage's aroma, taste, body, and color. Together, these compounds create the sensory aspects of coffee's flavor.

Coffee beverage flavors differ, not only because of differences in blend and roast but also because the water removes each flavoring compound at a different rate. For example, water readily extracts the aromatic portion. Although small and hardly measurable in relation to the total extract, aromatic compounds significantly contribute to the perception of beverage flavor. The compounds responsible for taste (which dissolve in the water) and for body (which don't dissolve) are less easily removed. Both sets of aromatic and taste compounds contain many different chemical components, which combine to produce different beverage flavors.

During brewing, the total amount of flavoring material in the beverage changes, as does the proportion of each compound. In other words, the flavor changes continuously as time elapses. As a general rule, the most flavorful compounds are extracted first. The longer coffee particles remain in contact with the water, the greater the quantity of less-flavorful compounds released. Prolonged extraction results in an unacceptable beverage flavor. The most desirable mixture of flavor elements occurs before you remove the maximum amount of material available. Consequently, for optimum results, you must stop the brewing process before the point of maximum extraction.

Six Essential Elements

Here are the six elements necessary to transform roasted beans into a good-tasting beverage:

1. **Correct coffee-to-water ratio.** The finished brew is a balance between strength (solubles concentration) and extraction (solubles yield). Shifting the balance either way greatly affects the final product. For example, coffee is an extremely concentrated flavoring agent and must be diluted with water. The most acceptable ranges of concentration fall between 1.0% and 1.5% coffee and between 99.0% and 98.5% water. Coffee strength less than 1% is too weak, and coffee strength above 1.5% is too strong. The most acceptable ranges of yield lie between 18% and 22%, with under-developed yields (those below 16%) creating flavors that are grassy to peanut-like and over-extracted yields (those above 24%) resulting in bitter and astringent flavors.

   It's also possible to extract a large amount of coffee flavoring material and dissolve it in a small amount of water or, conversely, to extract a small amount of material and dissolve it in a large volume of water. The brewing formula becomes the guide for selecting the proper coffee-to-water ratio to control both the solubles concentration and yield.

2. **A coffee grind that matches the brewing time.** Once you've established a coffee brewing formula, the method of brewing and the operation of the equipment come into play. To prevent under-development or over-extraction of the flavoring compounds, you must match the correct particle size (grind) of the coffee to the brewing method and type of equipment used. As a general rule, longer brewing times should be paired with larger (coarser) particles, and shorter brewing times should be paired with smaller (finer) particles.

3. **Proper operation of brewing equipment.** Brewing equipment normally controls three variables:

   - **Time of contact between the coffee grounds and water.** It takes time for the coffee particles to absorb the water, for the water to dissolve and extract the soluble material in the particles, and for the dissolved material to migrate into the beverage. Because water extracts different

chemical compounds from ground coffee at different rates, the mixture of soluble materials in the beverage changes continuously. Therefore, controlling the brewing time contributes to optimal extraction and produces uniform results.

- **Temperature of the water.** Cold water doesn't extract coffee as completely or as rapidly as hot water. Water that ranges in temperature from 195°F to 205°F (*92°C to 96°C*) liberates the aromatic materials more rapidly and permits proper extraction of other solubles within a reasonable time. As a general rule, the temperature should remain constant throughout the brewing cycle.
- **Turbulence.** As water passes through and over the coffee grounds, it creates a mixing action known as turbulence. Sufficient turbulence is necessary to first wet the coffee particles and then to cause the water to flow uniformly through them. Wetting allows the water to penetrate the particle fibers, and a uniform flow allows the soluble material to dissolve. In addition, adequate turbulence prevents the water that's in immediate contact with the coffee from becoming so saturated with dissolved material that it can no longer remove additional flavoring compounds.

4. **Optimum brewing method.** Using the same type of coffee in different brewing equipment will create coffee beverages with different taste and body characteristics. The equipment's design will use one of six basic methods to extract the flavoring materials from the ground coffee:
   - **Steeping.** In this brewing method, coffee grounds in a container are mixed with hot water, left in contact with the water for a specified length of time, and then separated from the extract or brew. The time of contact depends on the particle size, the water temperature, how much the grounds are agitated, and how quickly the grounds are separated from the beverage.
   - **Decoction.** Loose coffee grounds are mixed in a container with water that continues to boil for an arbitrary length of time. Complete extraction usually occurs during this preparation method, due to the elevated water temperature of 212°F (*100°C*) and the extreme turbulence created by the boiling water.
   - **Percolation.** The ground coffee is placed in a container that serves both as a brewing chamber and as a means of separating the grounds from the beverage. A pump moves the hot water to and through the coffee again and again. First the water, then the beverage extract, recirculates through the grounds. In this case, the time of contact depends upon grind size, the temperature of the water or extract, and the rate of recirculation.
   - **Drip filtration.** As with percolation, the grounds are placed in a container that serves both as a brewing chamber and as a means of separating the grounds from the beverage. In this method, however, the hot water flows through the coffee only once. The extract drips from the brewing chamber into a pot or other beverage receiver. The time of contact depends principally upon the rate that water flows into the brewing chamber and the size of the grind. Other important factors include the water temperature, the chamber's shape, and the type of filter.
   - **Vacuum filtration.** This method, which uses a two-chamber device, is a variation on the steeping method. Steam pressure forces hot water from the lower chamber up through a filtering unit and into the upper chamber, which contains coffee. Escaping vapor and stirring serve to agitate the coffee and water. When heat is removed after an arbitrary length of time, steam condenses in the lower chamber and creates a vacuum. The vacuum pulls the beverage down through the filter and into the lower chamber but leaves the grounds behind. The time of contact depends on how quickly a vacuum forms, the properties of the filter unit, and the particle size of the ground coffee.
   - **Pressurized infusion.** Pressurized water (between 2 to 10 atmospheres of pressure) is forced through the coffee grounds, which are compacted into a small cake in the brewing chamber. The combination of heat and the force of the water extracts soluble flavoring materials, emulsifies insoluble oils, and suspends both ultra-fine bean fiber particles and gas bubbles. This creates a beverage with an extremely high solubles concentration. To produce a uniform beverage with this method, rapid brewing times and extremely fine particle sizes are essential. The brewing temperature, 190-195°F (*88-92°C*), is slightly lower than for other methods.

   Most of these brewing methods will produce a quality coffee beverage; decoction and percolation are the exceptions because over-extraction leads to undesirable tastes.

5. **Good-quality water.** When preparing a coffee beverage, water is just as important as the coffee. In fact, water represents more than 98% of the beverage. Water that contains some minerals favors the development of optimum beverage tastes. As a

rule, water containing 50 to 100 parts per million (3 to 6 grains) of dissolved minerals will produce the best-tasting beverage. The water should taste like fresh, good-quality drinking water, have no odor, and contain no visible impurities.

Water that's very soft or very hard doesn't yield the most acceptable beverage and should be treated before being used for coffee brewing. For example, water filters can remove insoluble materials and sediments, and demineralization can remove excessive dissolved solids. Activated charcoal—or preliminary chlorination that's followed by an activated charcoal treatment—can take away odors. In many instances, polyphosphate treatment of the water will prevent scaling and corrosion of brewing equipment without affecting beverage flavor.

Water softening treatment that substitutes sodium ions for dissolved minerals **is not recommended** especially for water containing high concentrations of bicarbonate solids. This treatment often increases alkalinity, which has an undesirable physical effect on coffee's taste. In addition, this method of treatment will increase the coffee's contact time with water, causing over-extraction of the grounds and objectionable bitterness in the beverage.

6. **An appropriate filtering medium.** Unless something separates the extract from the coffee grounds, the resulting beverage will be murky and difficult to drink. Filters, to varying degrees, clarify the beverage by separating the insoluble material from the brew. As a result, the filtering method directly affects the body of the beverage—and indirectly affects the flavor of the beverage.

   Body, which contributes to flavor, is created in part by the insoluble materials that the water carries into the finished brew. These insoluble materials (principally oils and small particles of bean fiber) create brew colloids, which trap soluble material and gases that are later released on the palate. This time-delayed release of flavoring materials adds to the overall enjoyment of the beverage.

   Filters fall into four general categories:

- **Perforated metal plates.** These plates have holes that allow extract to leave the brewing chamber yet hold back some of the fine particles in the coffee grounds. The size and number of holes vary but must relate to the size of the grind used in the brewing equipment. Perforated plates provide virtually no clarification of the beverage, enabling most fine and very fine particles to pass through.
- **Woven wire screens.** Compared to metal plates, wire screens provide a greater number of smaller holes in the filter barrier. The screens can be woven to hold back different amounts of the fine particles but, compared to perforated metal plates, offer only slightly better clarification of the beverage.
- **Cloth.** Either sewn into bags or shaped to cover various forms, cloth can serve as a filtering medium. The type of cloth and weave determine its retentive capabilities. Very good beverage clarity can be achieved with material having, at most, a weave of 64 x 60 threads per inch and a weight of 5.75 square yards per pound.

  Before their first use, cloth filters require soaking and rinsing in hot water. With ongoing use, special procedures are necessary to prevent the filter from absorbing oils that later decompose and alter beverage flavor. Cloth filters should be stored in cold water after each use.
- **Paper.** Of the four types of filters, paper yields the clearest beverage. With paper, however, it's difficult to establish ideal brewing conditions: Paper is weak and, without adequate support, often resists the flow of beverage to such an extent that over-extraction occurs. Paper filters should be strong enough to permit the use of wire supports that don't impede the flow of extract. In addition, paper shouldn't transfer any tastes to the brew or by itself impede the flow of extract.

A Successful Transformation

Ultimately, the coffee beverage's quality depends on your ability to follow the steps outlined above. Even if you start with one of the world's finest coffees you may end up with a less-than-ideal beverage if, for example, you use an inappropriate brewing method or poor quality water. A successful transformation from beans to beverage requires understanding—and adhering to—these six essential elements of good brewing.

material had been removed from each pound (16 ounces) of coffee; or a .70 ounces yield from a 3.50-ounce batch; or that 2.00 grams were extracted from each measure (10 grams) of coffee used in preparing the brew.

Brewing Formula (Coffee-to-Water Ratio)

The coffee brewing formula is a ratio, which is defined as the weight of ground coffee to the volume of water used in preparing the brew. For simplicity, the brewing ratio is often expressed as the weight of coffee required to prepare a standard- size batch. For example:

- Grams of coffee per each serving, either 6 fluid ounces (180 ml) per standard U.S. cup or 125 milliliters (4.25 fl. oz.) per standard European cup for home brewing devices.
- Grams of coffee per liter of water for European brewers.
- Ounces of coffee for each 64 fluid ounces of water for half-gallon to gallon-and-a-half batch commercial brewers.
- Gallons of water per pound of coffee for urn brewers.

On the Coffee Brewing Control Chart, as shown in Diagram C, the diagonal lines that cross the chart from left to right represent brewing formulas. The specific coffee-to-water ratio is displayed across the top of the chart and down the right-hand side. Each diagonal line represents a different coffee-to-water ratio; the strongest ratios appear in the upper left-hand corner, and the weakest ratios appear in the chart's lower right-hand corner.

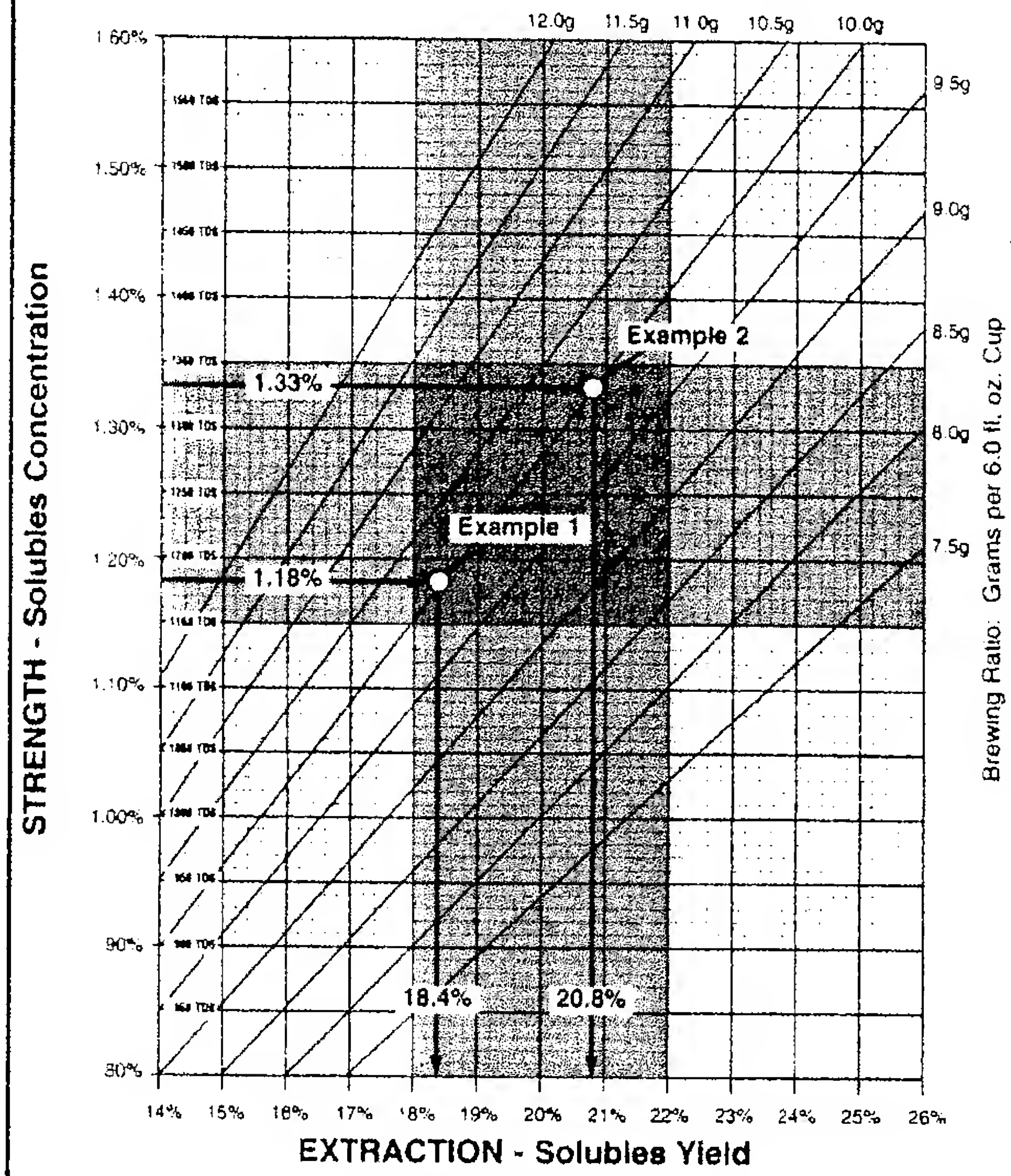
Once you've established a coffee-to-water ratio, you can draw a linear relationship between the strength of the beverage and the amount of soluble flavoring material extracted from the coffee. For any given brewing formula, increases in solubles yield will cause proportional increases in solubles concentration; decreases in solubles yield will cause proportional decreases in solubles concentration.

Assume, for example, you used 10 grams of coffee and 6 fluid ounces of water to prepare a single serving. If, during the brewing process, 1.84 grams of coffee flavoring material were removed (18.4% extraction), the resulting beverage would show a strength of 1.18% (1180 TDS) dissolved coffee flavoring material (See Diagram C, Example 1).

On the other hand, suppose you determined the resulting beverage showed a strength of 1.33% (1330 TDS) dissolved flavoring material. Then the yield of material removed from the grounds during the brewing process would be 2.08 grams (20.8% extraction) for this brewing formula (See Diagram C, Example 2).

DIAGRAM C

COFFEE BREWING CONTROL CHART
Brewing Ratio: Grams per 6.0 fl. oz. per Cup



Objective Measurement

This simple analysis clearly shows the relationship between strength and extraction. It's possible to remove a large amount of flavoring material and dissolve it in a small volume of water. This results in a beverage with a very high concentration of solubles—espresso is a good example. Conversely, it's possible to extract a small amount of material and dissolve it in a large volume of water. That would result in a beverage with a very low concentration of solubles—tea is a good example. To some extent, the brewing formula will control both solubles concentration and solubles yield (see Table 1).

If you know the values for any two of the three factors (strength, extraction, and brewing formula), you can calculate the value of the third. In this manner, **you can objectively measure and study the inter-relationships of the critical variables in the brewing process,** which involve the blend, roast, grind, time, temperature, turbulence, and water quality.

Subjective Evaluation

The coffee beverage derives its flavor from two sources: aroma (gases) and taste (liquids). During the brewing process, aroma is extracted much more rapidly than taste. In fact, the gases are almost immediately driven out of the grounds when they come in contact with hot water. (Compared with ground coffee the perception of aromatics decreases by 75% when the coffee is brewed.)

Table 1

Interrelationship between Soluble Solids, Extraction, and Brewing Formula

Soluble Solids, oz./gal.		0.07	0.13	0.27	0.40	0.54	0.67	1.34	1.47	1.61	1.74	1.88	2.01	2.14	2.28	2.41	2.55	2.68
Soluble Solids, %		0.05	0.1	0.2	0.3	0.4	0.5	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
		Brewing Formula, Gallons per Pound																
Extraction %,	oz./lb.																	
5	0.80	12.18	6.21	3.23	2.24	1.73	1.43	0.86	0.78	0.73	0.70	0.66	0.64	0.61	0.59	0.57	0.55	0.54
10	1.60	24.12	12.18	6.21	4.22	3.23	2.63	1.43	1.32	1.23	1.16	1.09	1.04	0.99	0.94	0.90	0.87	0.84
15	2.40	36.06	18.15	9.20	6.21	4.71	3.82	2.03	1.87*	1.73	1.62	1.52	1.43	1.36	1.29	1.23	1.18	1.13
16	2.56	38.45	19.34	9.79	6.60	5.01	4.06	2.15	1.98	1.83	1.71	1.60	1.51	1.43	1.36	1.30	1.25	1.19
17	2.72	40.84	20.53	10.39	7.01	5.31	4.30*	2.26	2.08	1.93	1.80	1.69	1.59	1.51	1.43	1.37	1.31	1.25
18	2.88	43.22	21.73	10.99	7.40	5.61	4.54	2.39	2.19	2.03	1.89	1.77	1.67	1.58	1.50	1.43	1.37	1.31
19	3.04	45.61	22.92	11.58	7.79	5.91	4.78	2.50*	2.30	2.13	1.98	1.86	1.75	1.66	1.57	1.50	1.43	1.37
20	3.20	48.00	24.12	12.18	8.19	6.21	5.01*	2.63	2.41	2.23	2.08	1.94	1.83	1.73	1.64	1.57	1.49	1.43
21	3.36	50.39	25.31	12.78	8.60	6.51	5.25	2.74	2.52	2.33	2.17	2.03	1.91	1.81	1.71	1.63	1.56	1.49
22	3.52	52.78	26.51	13.37	8.99	6.81	5.49	2.87	2.63	2.43	2.26	2.11	1.99	1.88	1.78	1.70	1.62	1.55
23	3.68	55.16	27.70	13.97	9.40	7.10	5.73	2.98	2.74	2.53	2.35	2.20	2.07	1.96	1.86	1.76	1.69	1.61
24	3.84	57.55	28.90	14.57	9.79	7.40	5.97	3.10	2.84	2.63	2.44	2.29	2.15	2.03	1.92	1.83	1.75	1.67
25	4.00	59.94	30.09	15.17	10.18	7.69	6.21*	3.22*	2.95	2.73*	2.54	2.37	2.23*	2.10	1.99	1.90	1.81	1.73
30	4.80	71.88	36.06	18.14	12.18	9.20	7.40	3.82	3.49	3.22	2.99*	2.80	2.63	2.48	2.34	2.22	2.13	2.03
35	5.60	83.82	42.03	21.13	14.17	10.69	8.60	4.42	4.04	3.72	3.46	3.22	3.02	2.85	2.69	2.58	2.44	2.33
40	6.40	95.76	48.00	24.12	16.16	12.18	9.79	5.01	4.59	4.22	3.91	3.65	3.43	3.22	3.04	2.90	2.75	2.63

Source: Coffee Brewing Center Publication No. 27

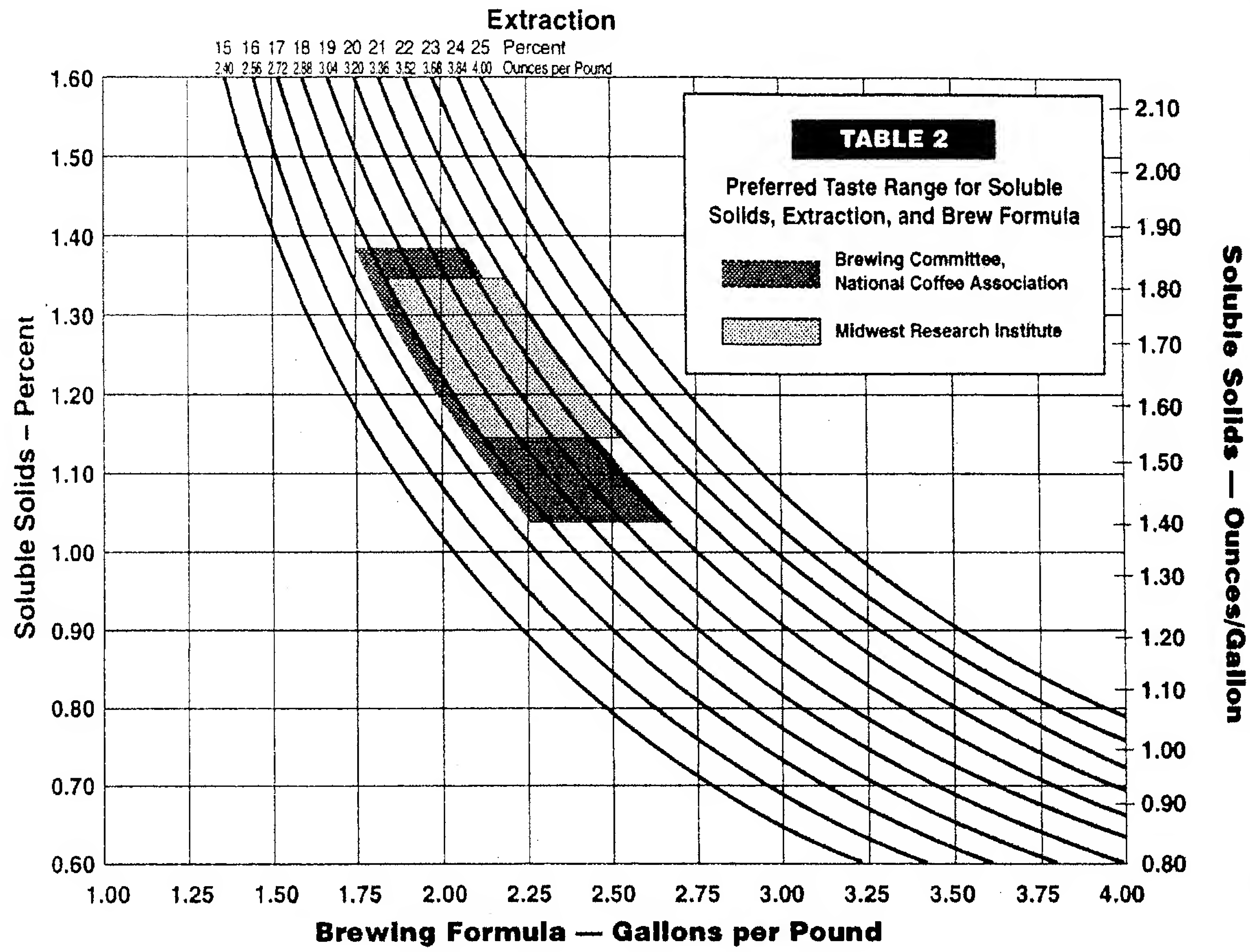
Although they're an important part of the overall flavor profile, the volatile aromatic components don't contribute to taste. The taste components come from the soluble flavoring material removed from the coffee grounds that remain in a liquid form. Flavoring material that does not dissolve (transform into a liquid) cannot be tasted. It does, however, create mouthfeel and is referred to as the coffee's body.

Compared to aroma, taste is extracted more slowly. Because body also slowly increases during the brewing period, taste and body are closely associated. Consequently, you can use the concentration of the dissolved flavoring material as a measure of taste and body build-up. When taken in conjunction with objective measurements that pinpoint solubles yields, subjective evaluations will confirm under-development —characterized by either undesirable grassy or peanut-like tastes due to low solubles yield—or over-extraction, which results in astringency and bitterness due to high solubles yield (see Table 2).

Balance Between Strength and Extraction

Repeated studies by the Coffee Brewing Center (CBC) identified three principles that define the relationship between strength and extraction. Later studies conducted by the Nordic Coffee Brewing Center confirmed these same principles:

1. A narrow range exists for extraction of the most flavorful soluble material. Solubles yields below 18% tend to have grassy and peanut-like tastes and are classified as "under-developed" tastes. Solubles yields above 22% tend to have unpleasant astringent and bitter tastes and are classified as "over-extracted" tastes. Extraction levels between 18% and 22% exhibit the most desirable flavors.
2. Concentration levels of soluble flavoring material have a broader range. Solubles concentrations below 1.15% coffee (1150 TDS) are considered "weak." They tend not to present the flavor of the coffee at an intensity where all of the components are above the taste threshold of the average person. Concentration levels above 1.35% coffee (1350 TDS) are considered "strong." They tend to present the flavor components at too intense a concentration to be easily perceived. For the average person, solubles concentrations between 1.15% and 1.35% tend to offer the most enjoyable level of intensity. (Note: Flavor intensity can also relate to the degree of the coffee's roast, which will cause the threshold between "too weak" and "too strong" to vary slightly for different roast values. Research done by the Coffee Brewing Institute and the Nordic Brewing Center involved roast values in the range of Agtron/SCAA color tiles #65 to #55.)
3. To reach the optimum flavor, solubles concentration needs to be in balance with solubles yield—in other words, **the most flavorful mixture of soluble flavoring material is presented at the most pleasing level of concentration.** To reach this **optimum balance** between strength and extraction (which CBC referred to as "Ideal"), brewing formulas must fall within these specified ranges:



Source: Coffee Brewing Center Publication No. 27

- 9.0 to 11 grams of coffee per 6 fluid ounces of water for single cup brewers—or 6.25 to 7.75 grams of coffee per 4.25 ounces of water for European *(125 mil.)* size cups.
- 50 to 60 grams per liter for brewers calibrated in the metric system. (Note: The Brewing Center of Norway recommends brewing formulas in the range of 60 to 70 grams of coffee per liter of water.)
- 3.25 to 4.25 ounces of coffee per 64 fluid ounces of water for half-gallon brewers.
- 2.5 to 2.0 gallons of water per pound of coffee for urn brewers.

With coffee-to-water ratios that exceed the specified range, it's impossible to maintain a solubles concentration level low enough to be pleasurable when removing all of the desirable flavoring material. On the other hand, if coffee-to-water ratios fall below the specified ranges, it is impossible to achieve solubles concentrations high enough to be pleasurable without removing the flavoring materials that cause the beverage to become astringent and bitter.

Brewing Analysis Graph

The Coffee Brewing Control Chart is excerpted from a larger Coffee Brewing Analysis Graph that depicts the full range of possible outcomes from any set of brewing parameters. The full graph starts at 0% on each axis and theoretically extends to 100% at each end. The working range of the graph actually extends to 2.00% strength and 35% extraction. Because the useful range for meaningful study of coffee brewing lies between .80% to 1.60% strength and 14.0% to 26.0% extraction, only this range appears on the Coffee Brewing Control Chart.

The Coffee Brewing Analysis Graph shows brewing ratios in grams per liter. You can convert these ratios to either ounces-per-half-gallon or gallons-per-pound using Tables 3 and 4.

Using the Chart

As noted above, the Coffee Brewing Control Chart allows you to study the inter-relationship between strength and extraction and to evaluate the various effects of changing the coffee's blend, roast, or grind. You can

CHAPTER 4
THE BREWING PROCESS

There's a craft in brewing good coffee. For any given product, the key lies in finding the optimum balance between the strength of the brew and the degree of extraction from the roast-and-ground coffee.

Strength refers to the brew's intensity—how concentrated it is—and needs to be adjusted for consumers' individual tastes, just as you'd adjust the volume on a stereo. Strength can be quantified as the percentage of solubles concentration in the brew. Extraction refers to the brew's acceptability—which specific flavoring materials have been removed from the grounds—and needs to be controlled to optimize taste, just as you'd adjust the mix of treble and bass coming from the stereo's speakers. Extraction can be quantified as the percentage of solubles yield from the amount of coffee grounds used in preparing the brew.

Aroma + Taste = Flavor

The strength of coffee is associated with the chemical compounds that hot water can extract from the roasted, ground beans. Some of these solubles evaporate easily and are responsible for the brew's aroma; others aren't so volatile and are the source of the brew's taste (See Table 1). Aroma and taste combine to produce coffee's flavor. The insoluble compounds—those that don't dissolve —become the coffee's body.

TABLE 1

Chemical Compositions of Soluble and Insoluble Portions of Roasted Coffee*

(Approximate, Dry Basis)

	% Solubles	% Insolubles
Nonvolatiles		
Carbohydrates (53%)		
Reducing Sugars	1-2	–
Caramelized Sugars	10-17	0-7
Hemi-cellulose (hydrolyzable)	1	14
Fiber (not hydrolyzable)	–	22
Oils	–	15
Proteins (N x 6.25); Soluble Amino Acids	1-2	11
Ash (oxide)	3	1
Acids (nonvolatile)		
Chlorogenic	4.5	–
Caffeic	0.5	–
Quinic	0.5	–
Oxalic, Malic, Citric, Tartaric	1.0	–
Volatile Acids	0.35	–
Trigonelline	1.0	–
Caffeine (Arabicas 1.0%; Robustas 2.0%)	1.2	–
Phenolics (estimated)	2.0	–
Volatiles		
Carbon Dioxide	trace	2.0
Essence of Aroma and Flavor	0.04	–
Total	**27-35%**	**73-65%**

**Source: Sivetz and Desrosier (1979)*

Roasted coffee contains vastly different amounts of aroma and taste materials. The beverage gets its taste from the extractable non-volatile materials, which potentially amount to about 30 pounds in each 100 pounds of coffee. In contrast, the extractable volatile materials amount to less than one-half ounce in each 100 pounds of coffee. In other words, the ratio of taste to aroma components is about 1,000 to 1. Consequently, the perception of beverage strength relates directly to the perception of taste.

The acceptability of the taste perception is also tied to the brew's chemical composition, which changes continuously during the brewing cycle. The changes occur because each flavoring compound dissolves at a different rate.

Three Phases of the Brewing Process

To achieve the optimum balance between strength and extraction, it's essential to control the brewing process. The brewing process itself proceeds in three stages:

1. **Wetting.** As the bean fiber absorbs hot water, gas is driven from the coffee particles and interstitial voids (the small spaces inside the particles). This phase prepares the particles for extraction of the solubles.
2. **Extraction.** During this second phase, the water-soluble flavoring compounds dissolve, rapidly moving out of the bean fibers and entering the water.
3. **Hydrolysis.** At this point, large molecules of water-insoluble carbohydrates break down into smaller molecules that are water soluble. These are mostly reducing sugars but also include some proteins.

24 Variables of Coffee Brewing

Because the brewing process proceeds in three distinct phases—wetting, extraction, and hydrolysis—the design and operation of the brewing equipment have a direct bearing on the composition of the flavoring material in the brew. Therefore, controlling the brewing process means controlling the variables related to the coffee as well as the variables related to the brewing equipment.

In total, 24 variables interact during the brewing process. Controlling all these variables to achieve the optimum balance between strength and extraction is a true craft. The variables can be categorized as follows:

Coffee Product

The coffee roaster usually has the responsibility for controlling the 10 variables related to the coffee product.

- **Blend components.** The **(1) ratio of different coffees** used in the blend can range from a single-origin coffee on one extreme to a mix of arabica and robusta coffees on the other. Also affecting the

TABLE 2

Variables Affecting Strength and Extraction

Coffee Product		
Blend Components:	1.	Ratio of blend components
	2.	Bulk density of beans
	3.	Chemical composition of beans
Roast Development:	4.	Methodology of roasting
	5.	Rate of roasting
	6.	Degree of roast
	7.	Rate of degassing
Grind:	8.	Average size of particles
	9.	Size distribution of particles
	10.	Particle shape
Brewing Equipment		
Time of Brewing:	11.	Time of water contact
Temperature:	12.	Contact temperature
	13.	Temperature gradient during brewing
Turbulence:	14.	Complete wetting
	15.	Uniform flow
	16.	Particle movement
Filtering Method:	17.	Method of separation
	18.	Degree of clarification
Holding Conditions:	19.	Length of time and method of holding
	20.	Holding temperature
Ingredients		
Brewing Formula:	21.	Coffee (by weight)
	22.	Water (by volume)
Water:	23.	Water composition
	24.	Water treatment

blend is the beans' (2) **bulk density**—a measure of the beans' weight in relation to their physical volume. Finally, the (3) **chemical composition** of the beans themselves affects the brew's resulting flavor and intensity. Chemical composition varies by the type of coffee plant and the micro-climate in which it grows.

- **Roast development.** The (4) **methodology of roasting,** particularly the efficiency of heat transfer within the beans, determines if the beans are uniformly roasted from the outside to the center of the bean. The (5) **rate of roasting controls** both the structural expansion of the bean fibers (which affects extraction rates) and the chemical composition of the roasted beans (which affects the flavor of the extract). Other variables include the (6) **degree of roast,** usually evaluated by the beans' color, and the (7) **rate of degassing,** which generally relates to the method of storage or length of time before brewing.
- **Grind.** Relative to brewing, a critical aspect of the coffee product is the grind, or particle size. Within certain limits, the amount of soluble material extracted from the coffee varies inversely with the particle size: The smaller the particles, the greater the extraction (See Table 3). In controlling the particle size, both the (8) **average size** of the particles and the (9) **size distribution** of the particles creating the average must be taken into account (See Table 4). In addition, the (10) **particle shape** will affect the rate at which soluble material can be extracted from the coffee.

TABLE 3

Effect of Particle Size of Coffee Grounds on Extraction of Soluble Solids

Particle Size (Tyler Screen #)	Contact Time (in seconds)	Soluble Solids (as percent)	Extraction (oz./lb.)
on #10	142	0.63	1.67
on #14	143	0.73	1.93
on #20	136	0.93	2.45
on #28	156	1.28	3.40
on #40	292	1.46	3.87

- Water:coffee ratio at 2¼ gallons per pound
- Water temperature at 200° F
- Results averaged from five trials with each size fraction

Source: Coffee Brewing Center, Publication #40

Brewing Equipment

Ten of the variables balancing strength and extraction relate to the brewing equipment. Of these, six involve time, temperature, and turbulence, which are usually controlled by the equipment manufacturer.

TABLE 4

Particle Size and Distribution for Typical Grinds

	Regular	Drip	Fine
Percent on			
#10 mesh	13%	0%	0%
#14 mesh	20%	7%	0%
#20 mesh	25%	33%	10%
#28 mesh	30%	40%	60%
Percent thru			
#28 mesh	12%	20%	30%

Source: Coffee Brewing Center, Publication #118

- **Time of brewing.** The (11) **contact time**—how long coffee remains in contact with the water—determines the percentage of solubles yield. The longer the contact time, the greater the extraction of soluble materials. Generally speaking, rapid extraction occurs during the first third of the brewing cycle, yielding as much as 70% of the available soluble material.
- **Temperature.** For proper extraction to occur, water must reach the coffee at (12) **contact temperatures** near 200°F *(94°C)* and the (13) **temperature gradient** must remain in a constant range between 195°F to 205°F *(92-96°C)* (See Table 5).
- **Turbulence.** Turbulence is affected by the way the water is distributed over the bed of grounds, leading to (14) **complete wetting** of the coffee; the velocity of the water flowing through the coffee bed, creating a (15) **uniform flow rate**; and the bed's size, depth, configuration, and degree of containment, limiting the (16) **particle movement.** The design of the brewer's spray head and brew basket controls turbulence. A successful design results in complete wetting of all of the coffee particles in the brew basket, a uniform flow of water through the entire bed of coffee, and a separation of the particles while they are in contact with the water.

TABLE 5

Effect of Change in Water Temperature on Beverage Solids and Extraction from Grounds

Temperature (°F)	Beverage Solids (as percent)	Grounds Extraction (oz./lb.)
205	1.22	2.85
195	1.30	3.00
185	1.24	2.87
165	1.11	2.58
125	0.98	2.08
85	0.63	1.48

- Urn grind coffee
- Water:coffee ratio at 2.00 gallons per pound
- Time of contact at 3 minutes

Source: Coffee Brewing Center, Publication #40

CHAPTER 6
TIME, TEMPERATURE, AND TURBULENCE

The brewing process starts the moment hot water touches the coffee grounds and stops when the water and coffee grounds are separated. The period during which the water remains in direct contact with the coffee is known as the brewing time. The most desirable beverage results when the brewing process is completed within the time period prescribed for the coffee's grind.

Using a fine grind of coffee, the correct brewing time would range from 1 to 4 minutes. A drip grind requires 4 to 6 minutes, and a regular grind calls for a 6- to 8-minute brewing time. These times apply regardless of the equipment used or the quantity being prepared. The finer the grind, the greater the surface area exposed to the water. That means the dissolved flavoring materials have a shorter distance to travel to reach the water; therefore, the solubles extraction is more rapid and thorough.

Hot water removes the coffee-flavoring solubles effectively and rapidly. This holds true both in quantity and quality. The coffee brew extracted during the beginning of a brewing cycle is very dense and dark caramel in color. As water extraction continues, the eluted (extracted) beverage becomes less concentrated and lighter in color. Near the end of the brewing cycle, the extract is pale and appears almost like water.

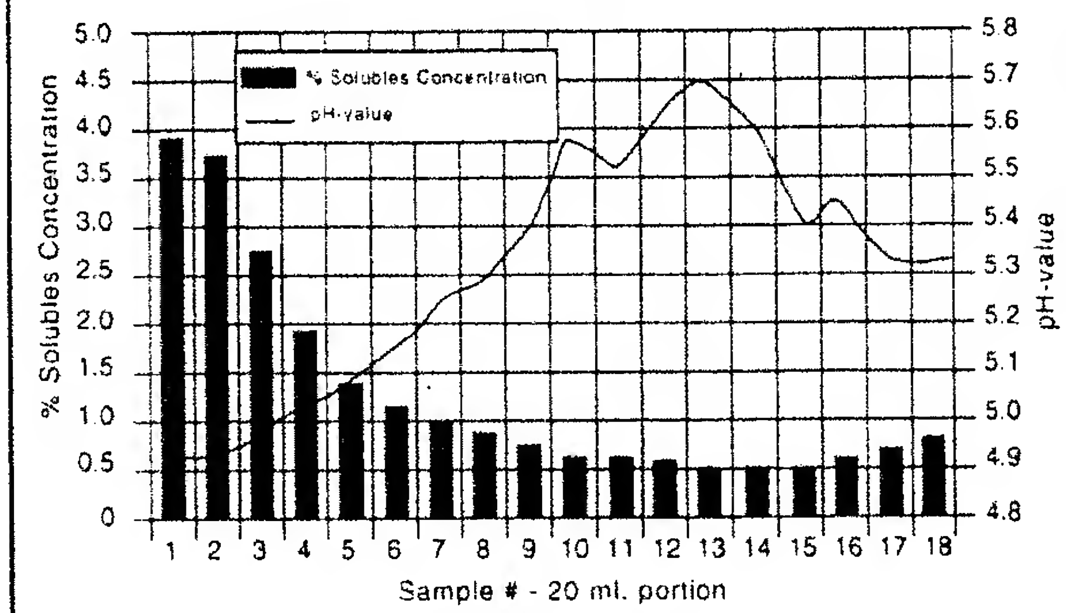
If you analyzed the coffee brew in terms of its flavor, as quantified by the solubles concentration and pH of the eluted beverage (See Diagram 1), you'd find that the extract removed during the first third of the brewing process (samples 1-6) would have the best flavor with the least bitterness and astringency. It would also have the highest solubles concentration (ratio of coffee flavoring material to water) than at any other point in the brewing cycle, as well as the lowest pH (greatest acidity). If you analyzed the coffee brew during the second third of the extraction process (samples 7-12), this effluent would have an average solubles concentration three times lower than the first third, while exhibiting a decrease in acidity of almost five times the level of the first third.

If the brewing cycle continues through the final third (samples 13-18), the effluent coffee beverage would be unpalatable. During this phase, the desirable solubles have been exhausted and the solubles that produce bitterness and astringency have become dominant. The point at which bitterness and astringency dominate the coffee's taste characteristics is referred to as over-extraction.

DIAGRAM 1

FLAVOR ANALYSIS

% Solubles Concentration and pH Value



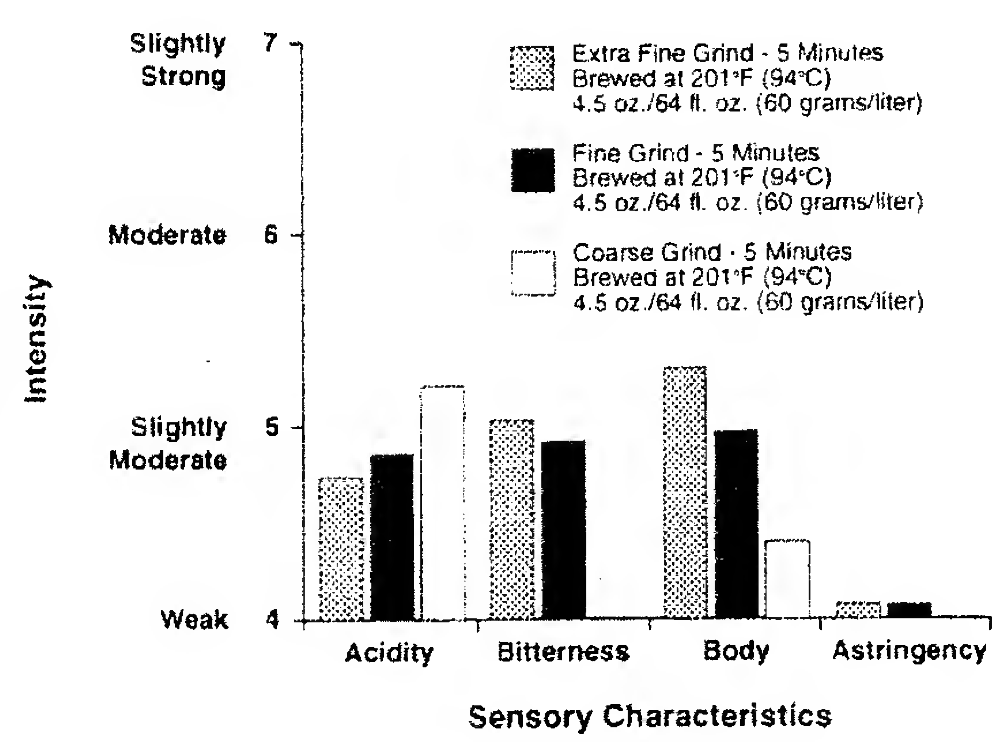
SOURCE: Braun Inc - engineering study

Time's Relationship to Extraction

As shown in Figure 1, controlling the grind is the most effective way to control the bitterness and astringency associated with over-extraction. Making the particle sizes larger will noticeably decrease these two taste flaws without seriously reducing the brew's acidity or body.

FIGURE 1

Effect of Grind Size on Coffee Taste and Mouthfeel



Source: ICO Technical Unit - Quality Series - Report No. 9

Chemical analyses indicate that all coffee brews contain very low concentrations of amino acids. However, those made from coarsely ground coffee contain a lower concentration of amino acids compared to brews made from finely ground coffee. Similarly, concentrations of other non-volatile acids vary with grind sizes. Acetic, citric, malic, and phosphoric acids appear in lower concentrations in brews made from coarsely ground coffee compared to brews made with either finely or extra finely ground coffees. Quinic acid increases as the grind size decreases, but the differences among concentrations are small.

Like all salts, there is a correlation between the concentration of the salt and its perceived taste. Increasing concentrations of potassium initially start as sweet, change to bitter, become salty and finally become sour. It is also possible that the potassium present in the brew is interacting with other taste components by modulating the type or intensity of their taste stimulation. Further research is needed to more fully understand the potassium's effect on the brew.

TABLE 6

Estimated Coffee Ash Distribution

	Green Coffee	Roast Coffee	Soluble Powder	Dry Spent Grounds
Dry weight relations'	1.176	1.000	0.380	0.620
Percent ash content, dry basis	4.00	4.71	10.00	1.47
Weight ash per unit weight roast coffee, dry basis	0.0471	0 0471	0.0380	0.0091

Percentage Distribution of Ash Components

Mineral Oxide	Percent of Total: Green, Roash Ash %	Solubles Ash % Total	Solubles Ash % Sol	Grounds Ash % Tol.	Grounds Ash % Grds.
K_2O	62.5	52.0	75.59	10.5	33.65
P_2O_3	13.0	3.0	4.36	10.0	32.05
CaO	5.0	2.0	2.90	3.0	9.62
MgO	11.0	8.0	11.63	3.0	9.62
Fe_2O_3	1.0	0.4	0.58	0.6	1.92
Sa_2O	0.5	0.4	0.58	0.1	0.32
SiO_2	1.0	—	—	1.0	3.21
SO_3	5.0	2.0	2.90	3.0	9.61
Cl	1.0	1 0	1.46	—	—
	100.0	68.8	100.0	31.2	100.0

' Assuming 15 percent weight loss on roasting.

Source: Sivetz and Desrosier, Coffee Technology

Turbulence's Infulence on Brewing

After time and temperature, turbulence is the third factor that affects coffee brewing. Turbulence causes coffee particles to separate and thereby allow for a uniform flow of water through and past them. Without sufficient turbulence, the water will fail to uniformly extract flavoring materials from all portions of the coffee bed. In this situation, some sections of the coffee bed are under-extracted, adding grassy to peanut-like flavors to the brew, while other sections are over-extracted, mixing bitter and astringent tastes into the brew.

The three aspects of turbulence are:

1. **Wettability** of the coffee grounds. For extraction to occur, the coffee particles must first absorb water. Wettability, a characteristic of roast-and-ground coffee, relates to the coffee's ability to absorb water at a uniform rate. As a general rule, each ounce of coffee will absorb two ounces of water *(each gram will absorb 2.086 milliliters of water).*

   Principally, the interstitial voids within each particle of coffee absorb the water. Once the water has completely surrounded a coffee particle, both inside and out, the coffee flavoring material begins to move out of the bean's cellular structure and into the surrounding water.

   Some coffee particles accept water more readily than others. This condition can be attributed to a variety of factors, including the origin of the coffee, the age of the green coffee, non-uniform roasting of the coffee bean, or an excess of oil surrounding the cellular structure of the ground particle. Surges of carbon dioxide gas from freshly ground coffee, which form a protective envelope around each particle, can also contribute to incomplete wetting. In addition, unusually high concentrations of minerals in the brewing water, particularly calcium (Ca) and sodium (Na) bicarbonate (HCO_3), will interfere with the wetting process.

   Non-uniform wetting causes inconsistent extraction. It tends to create a channeling of the water flow; some portions of the coffee bed are over-extracted, due to excessive water flow, while other portions deliver under-developed flavors because the coffee particles weren't fully extracted. This problem becomes readily apparent in equipment using relatively short brewing times, particularly single-cup brewers.

2. **Control of the bed height.** The coffee bed must be level and in gravity-fed brewing systems should measure from 1 to 2 inches *(2.5-5.0 cm)* in depth. If the brewing equipment doesn't meet these conditions, under- or over-extraction and inconsistency follow.

   Beds less than 1-inch *(2.5 cm)* high will lead to a light, bitter brew. Those that exceed 2 inches *(5.0 cm)* slow down the cycle and channel the water flow, thus creating off-flavors and a bitter taste. Channeling results when water follows the path of least resistance through the coffee bed. The water bypasses many sections of the coffee, leaving them completely dry. Areas where the coffee is mounded tend to cause over-extraction, while cavities tend toward under-development of the flavor.

3. **Proper feed of the brewing water over the coffee bed**. For uniform wetting and extraction of the coffee flavoring material to occur, the brewing water must lift and separate each coffee particle. Improperly applying water to the coffee bed can contribute to a faulty brew. Correct water feed depends upon the brew basket and spray head working in concert.

   In addition to creating the proper bed depth of 1-2 inches *(2.5-5.0 cm)*, the brew basket must be large enough to allow the coffee grounds to expand.

CHAPTER 8
FILTERING DEVICES

The primary purpose of the filtering device is to separate the grounds from the coffee beverage after the brewing cycle has concluded. The device usually consists of two parts:

1. **A rigid structure** that shapes and contains the bed of coffee grounds as water passes through them.
2. **A filtering medium**—usually wire mesh, woven fabric, or pre-formed paper—that prevents the grounds from passing through into the finished beverage.

When operating effectively, the filtering device also achieves the following objectives:

- **Provides a level bed of coffee.** This is necessary for uniform extraction from each particle of coffee. In general, this is accomplished manually as you place the grounds in the filtering device. If the coffee bed isn't level—if some sections are deeper than others—the water won't pass through at an even rate. As a result, some sections will be more highly extracted than others. The net result is uneven extraction throughout the bed of coffee.
- **Provides a proper depth of the bed of coffee.** For the best results, the filter device should provide a bed depth of 1.5 inches *(3.8 cm)*, plus or minus .5 inches *(1.2 cm)*. (See Appendix A for equations relating coffee volumes to the size of filtering devices.)

  If the bed is too thin, less than 1-inch *(2.5 cm)* deep, the water will pass through it too rapidly. The result will be weak, poorly extracted coffee. Beds that exceed 2 inches *(5.0 cm)* in depth lend themselves to the possibility of channeling. This occurs when water, in following the path of least resistance, sets up a channel through which it flows most readily. Some areas in the bed of coffee will remain completely dry, while the coffee grounds surrounding the channels will become over-extracted. Channeling results in bitter, unpleasant flavors.
- **Supports the grounds so they don't touch the finished beverage.** If you leave the grounds hanging in the brew, you extend the brewing time indefinitely. The result is over-extraction. Also, separating the grounds after brewing becomes more difficult because a large volume of finished beverage surrounds the coffee bed, requiring additional time for complete drainage.
- **Provides multiple drainage points.** More than one point is necessary to promote uniform flow of the water through the coffee bed. This ensures proper wetting and extraction of the coffee grounds. At the same time, multiple points prevent over-extraction of those parts of the coffee bed that would otherwise remain in prolonged contact with the water.

  Wire screens and perforated metal plates perform this important function if kept clean and unclogged. Cloth filters generally require special shapes and support devices to prevent them from sagging, which would cause the water to drain in a single stream from the lowest point. Paper filters require some type of supporting grid or cradle. Otherwise, the paper collapses against the brew-basket wall and limits the drainage area to a small center section of the filter.
- **Allows water to pass through in the proper amount of time.** Using a fine grind of coffee, the correct brewing time ranges from 1 to 4 minutes. For a drip grind, the appropriate time is 4 to 6 minutes; a regular grind requires 6 to 8 minutes. These times apply regardless of the equipment used or the quantity being prepared.

  Ideally, the filter retards the flow of the water long enough to create a slight steeping of the coffee particles. This brief steeping period allows the coffee flavoring material to migrate from the center of the coffee particles to the surface, where it enters into solution with the water flowing past. If the water passes through the coffee particles too rapidly, rinsing occurs: The water removes flavoring material only on or near the surface of the coffee particles.

  To create the optimum flow rate, perforated plates and metal discs need a sufficient number of properly sized holes. For example, wire-mesh screens should range from 60 to 100 mesh to adequately separate the coffee particles from the brew while still allowing the water to flow freely through the coffee bed. In cloth filters, the weave of the material will control the flow rate. Paper filters also have varying degrees of permeability. Select both cloth and paper filters on the basis of which permeability will provide the correct flow rate for the brewing application.
- **Allows the desired amount of undissolved materials, both sediment and oils, to pass into the final beverage.** This is the most important role played by the filtering device. Removing the oil and undissolved material (often referred to as sediment) is known as clarification. The degree of clarification is largely a matter of personal choice. Turkish coffee brewed in ibriks, for example, is served without any physical separation of the

grounds. At the other extreme is instant coffee, which is completely water soluble and contains no oil or sediment. It's virtually lacking in body or mouthfeel.

The type of filter directly affects the body of the finished brew which, in turn, affects the flavor of the beverage. The body is created by the insoluble materials, principally oils and micro-fine pieces of bean fiber, that are rinsed off the coffee particles. These insoluble materials create brew colloids, which trap soluble flavoring materials and gases in the brew. The colloids break apart as you drink the coffee, simultaneously releasing the aromas in your palate as the brew reaches your taste buds.

This simultaneous presentation of taste and aroma creates coffee's flavor. Because the filter controls the amount of brew colloids present in the finished brew, it has a direct bearing on the formation and retention of beverage flavor. Brew colloids create a time-delayed release of flavoring materials that adds to the overall enjoyment of the beverage.

Metal and Cloth Filters

In terms of promoting or retarding formation of brew colloids, each type of filter has advantages and disadvantages. In addition, some are easier to use or less expensive to buy. For example, metal plates, discs, and woven screens cost more to purchase initially. Compared to the costs of disposable cloth or paper filters, however, they're far less costly over the life of the equipment.

Wire screen sizes from 100 to 200 mesh completely separate the grounds from the finished brew yet still allow both oil and bean fibers to pass through and form large numbers of brew colloids. But these devices require constant attention and frequent cleaning. If not properly maintained, they become clogged with coffee oils and residues that produce off-flavors. If roughly handled, their pores may become ruptured; this results in excessive and localized leakage of ground particles into the finished brew.

Cloth filters require the most attention to remain clean and free from foreign materials that can migrate into the beverage. If the cloth is of poor quality or if the stitching stretches, the beverage will be muddy and contain excessive sediment. Another difficulty in using cloth filters can be traced to the vegetable origin of the material used in their manufacture. The constant and high temperatures required by the brewing equipment accelerate the breakdown of cloth fibers and increase the variety of chemicals absorbed into the cloth.

The weave of the cloth will affect both the flow rate of the water through the bed of coffee and the degree of beverage clarification. In the typical manufacture of cloth urn bags, muslin offers the fastest flow rate and the least clarification; flannel offers the slowest flow rate and the greatest clarification of the brew. In general, you can achieve excellent beverage clarity by using material that has a weave of 64 x 60 threads per inch and a weight of 5.75 square yards per pound.

Pros and Cons of Paper

Although chemical laboratories have used filter papers for more than 100 years, the coffee industry began using them relatively recently. The application can be attributed to a coffee brewer, in the shape of an hourglass, exhibited in New York City's Museum of Art in 1943. The brewer, which featured a paper filter, received an award in 1958 for one of the best-designed products of modern times. Filter paper played a big part in the commercialization and widespread use of the half-gallon brewer.

Paper-filter brewers offer a number of advantages. The paper provides a high degree of beverage clarity and controls the flow rate of water through the coffee bed. Paper filters don't clog or permit excessive brewing times. In addition, they're very easy to handle—rather than cleaning the filters, you simply dispose of them along with the spent grounds.

However, paper filters have a number of potential drawbacks. For filter paper to give consistent results, it must not shed its fibers. It should be free of pinholes, possess an even texture, remain resistant to temperature, and have high wet-strength properties. If the paper's fluting and shape don't hold up during brewing, the filter will fall away from the sides of the brew basket and possibly cause the water to bypass the coffee bed.

Most important, **filter paper shouldn't leave an aftertaste**. Unfortunately, most filter papers aren't taste free. Because of its porosity, paper easily absorbs foreign odors that are readily transmitted to the coffee beverage. To combat this problem, filter papers must be properly packaged and stored to prevent contamination from external sources and to prevent the development of mold or mildew.

The speed of beverage filtration has a direct bearing on the paper's contribution to taste. Highly permeable paper filters spend less time in contact with the coffee brew, thereby reducing their taste contribution to a low or negligible level. Slower filter papers tend to impart more of their taste to the finished brew.

The filter device forms an integral part of the coffee brewer because it can affect contact time and water turbulence. Even if the brewer stipulates the use of one type of filter, you can usually select the quality of filter you use. In that way, you can chose the proper filter to achieve your desired level of convenience and beverage clarity.